Wind Direction Estimates from Synthetic Aperture Radar Imagery of the Sea Surface

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LONG-TERM GOALS

We will investigate the range of near-surface mean wind directions with respect to the orientation of common marine atmospheric boundary layer (MABL) quasi-two dimensional phenomena seen in synthetic aperture radar (SAR) imagery of the sea surface. In doing so, we will provide empirically derived guidelines on how to distinguish the SAR-signature of one feature from another.

We will provide the impact of position errors in numerical weather model-analyzed synoptic scale storms and fronts on the wind-direction dependent retrieval of wind speed from SAR. This will be accomplished via a thorough error analysis of CMOD-4 with an emphasis on wind direction errors at varying incidence angles, and varying locations along the upwind/downwind/cross-wind quadrants.

OBJECTIVES

We will investigate the range of near-surface mean wind directions with respect to the orientation of common MABL quasi-two dimensional phenomena seen in SAR imagery of the sea surface. We will provide empirically-derived guidelines on how to distinguish the SAR-signature of one feature from another (see Figure 1 for examples of quasi-two dimensional phenomena seen in SAR imagery of the sea surface). We have outlined the scope of this portion of the research in Sikora and Young (2002). The quasi-two dimensional MABL phenomena that we will study are elongated cellular convection, buoyancy-driven / shear-organized roll vortices, inflection point-induced roll vortices, shear-driven gravity waves, and topographically-driven gravity waves.

We will provide the impact of position errors in numerical weather model-analyzed synoptic scale storms and fronts on the wind-direction dependent retrieval of wind speed from SAR via a thorough error analysis of CMOD-4 with an emphasis on wind direction errors at varying incidence angles, and varying locations along the upwind/downwind/cross-wind quadrants (see Figure 2 for an example of such an error). We will use the results of this error analysis to develop automated or semi-automated detection and correction algorithms for displaced cyclones and frontal wind shift lines. These algorithms will improve the accuracy of SAR wind speed retrieval in conjunction with model-analyzed wind direction fields.

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APPROACH

The basis of the feature-identification research will be SAR imagery provided to us at no cost by collaborators at Johns Hopkins University Applied Physics Laboratory (JHUAPL). This SAR

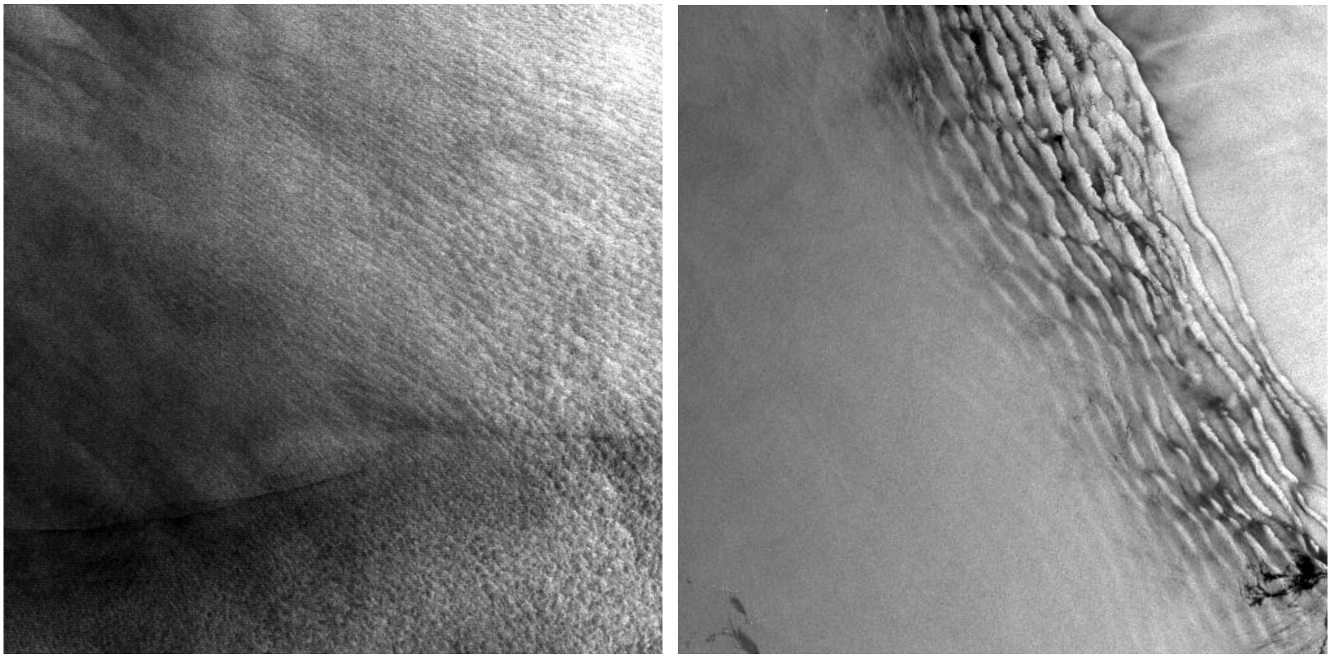

Figure 1. Radarsat-1 SAR image (left) depicting the signature of roll vortices. The 300 m pixel image is approximately 270 km by 270 km. The image was acquired at C-band, horizontal polarization, off the north east coast of the United States at 2242 UTC on 6 March 1997. The top of the image is directed towards 348^{o}T. (Provided courtesy of JHUAPL, © CSA) ERS-1 SAR image (right) depicting the signature atmospheric gravity waves associated highly ageostrophic flow near a front. The 180 m pixel image is approximately 90 km by 90 km. The image was acquired at C-band, vertical polarization, over the Caspian Sea at 0723 UTC on 12 May 1996. The top of the image is directed towards 012^{o}T. (Provided courtesy of Werner Alpers and ESA, © ESA)

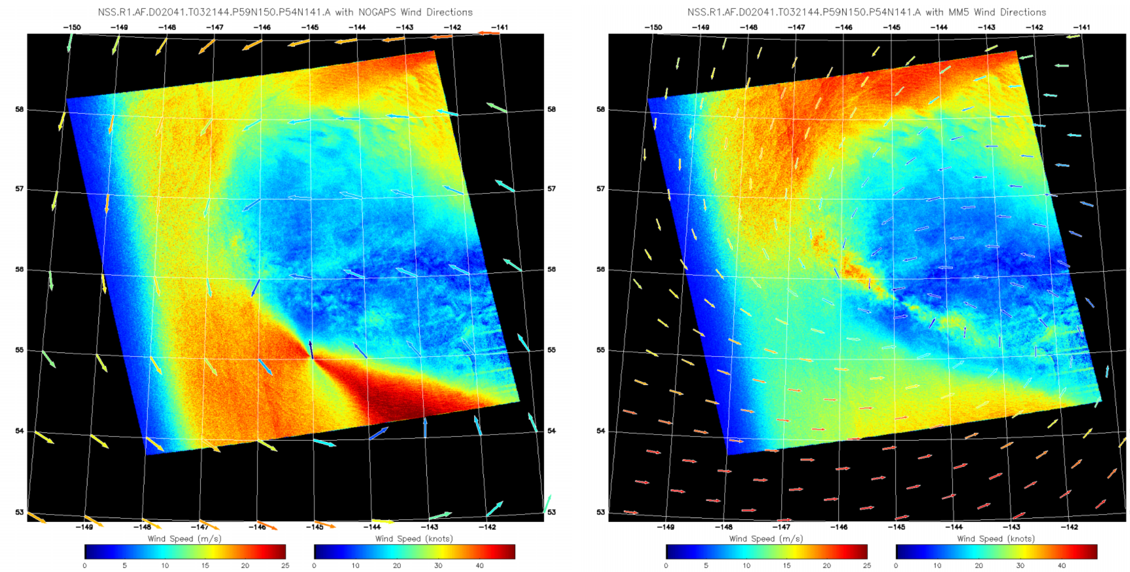

Figure 2. SAR wind speed images for 10 February 2002 generated by the Johns Hopkins University Applied Physics Laboratory. The image on the left was generated using NOGAPS wind directions. The image on the right was generated using MM5 wind directions. Both images contain an example of an erroneous hour-glass signature (at approximately 55^o N, -145^o for the NOGAPS image and at approximately 57.5^o N, -145^o for the MM5 image) resulting from the mis-positioning of the same cyclone center by NOGAPS (left image) and MM5 (right image). Arrows denote the corresponding model wind speed and direction.

imagery will be cross-referenced with corresponding in situ, remote sensing, and modeling data (also available at little or no cost). This supporting data will be used to assess both the type of phenomena depicted in a given SAR scene and the relationship between its orientation and the near-surface mean wind direction. Given that hundreds of SAR images of both the Northwest Atlantic Ocean and the Northeast Pacific Ocean are available to us, our study will provide a robust assessment of both feature orientation with respect to near-surface mean wind direction and of how to discern one feature from another. Using this knowledge, we will endeavor to develop image-processing algorithms mimicking our ability to distinguish between quasi-2 dimensional phenomena based on their structure in the SAR backscatter field. With these algorithms it will be possible to automate the determination of the relative angle between near-surface wind direction and the alignment quasi-2 dimensional features in the SAR imagery.

The basis of the numerical weather model-correction research will be SAR wind imagery provided to us at no cost by collaborators at Johns Hopkins University Applied Physics Laboratory (JHUAPL). Correction of model wind direction fields for misplaced synoptic features follows three steps: First, detection and location of the SAR error signature. Second, reposition the cyclone center or frontal wind shift line to eliminate this error. Third, morph the surrounding model wind direction field so that the far field is unaffected by the position correction. For the cyclone misplacement problem, the first step involves locating the model-analyzed vortex and then quantifying the degree to which the SAR derived wind speed field around the cyclone center matches the position-error signature. If the signature pattern explains at least 80% (a tunable parameter) of the variance, the vortex is classed as misplaced and the maximum range for which this condition is met is used as a measure of the error-

signature size. The alignment of the vortex misplacement signature is noted. Determination of the vortex displacement vector follows from this signature alignment. By displacing the model wind direction field to two new positions, one left of the signature alignment and other right, two new error signatures can be derived and their orientations used to triangulate the true vortex position. The offset distance should be proportional to the error signature size (a second tunable parameter - but highly dependant on the value used for the first). The final wind direction field is created by position dependent stretching. The center is displaced to its true location while points at greater radii from the center are displaced less, i.e. a single control point morphing. The diameter of the region affected should be proportional to the displacement distance with the constant of proportionality being a third tunable parameter. Frontal position correction will follow the same three steps although triangulation will not be required for computing displacement of a linear feature. Depending on our success in developing an automatic detection algorithm for the more subtle frontal position error signatures, human analysis of frontal position and displacement may be required.

WORK COMPLETED

We have outlined the feature-identification portion of this research in Sikora et al. (2004). We are further elaborating on the synoptic-scale portion of this feature identification in a manuscript currently being prepared.

RESULTS

This research is ongoing. We have not yet met our objectives.

IMPACT/APPLICATIONS

The research described herein fulfills ONR objectives by working towards the integration of standard meteorological theory and synthetic aperture radar data with the goal of providing high-resolution remotely sensed estimates of near-surface wind speed and direction in *in situ* data-sparse regions over the ocean, including the coastal zone.

REFERENCES

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Sikora, T. D., G. S. Young, R. C. Beal, F. M. Monaldo, P. W. Vachon, and N. S. Winstead, Applications of synthetic aperture radar in marine meteorology. *Advances in Fluid Mechanics: Atmosphere - ocean surface interactions*, William Perrie, Ed., Wessex Institute of Technology, in review

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